OLED LIGHTING: SHEET-TO-SHEET AND/OR ROLL-TO-ROLL-PROCESSING - CURRENT STATUS AND RESEARCH TOPICS

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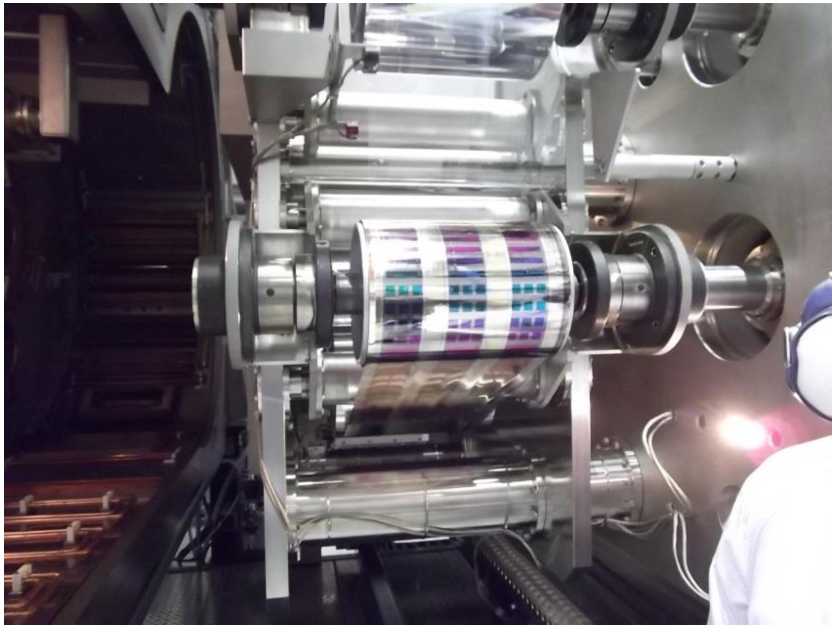
2016 DOE SSL R&D Workshop, Raleigh, NC, Feb 03 2015



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FRAUNHOFER FEP: FACTS AND FIGURES

- Fraunhofer FEP is one of 67 Fraunhofer within Fraunhofer Gesellschaft, Europe’s largest application-oriented research organization
- Fraunhofer COMEDD merged within Fraunhofer FEP July 1st, 2014: Fraunhofer Institute for Organic Electronics, Electron Beam, Plasma Technology (FEP)

- Director: Prof. Dr. Volker Kirchhoff
- Figures 2014: employees 193, total budget 25.0 M€, industry returns 8.6 M€, public funding 9.7 M€, investments 1.4 M€

- Core competences:

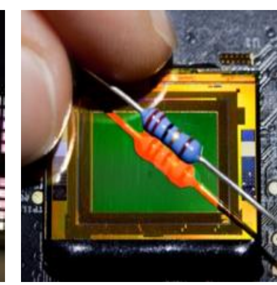
ELECTRON BEAM TECHNOLOGY

SPUTTERING TECHNOLOGY

PLASMA-ACTIVATED HIGH-RATE DEPOSITION

HIGH-RATE PECVD

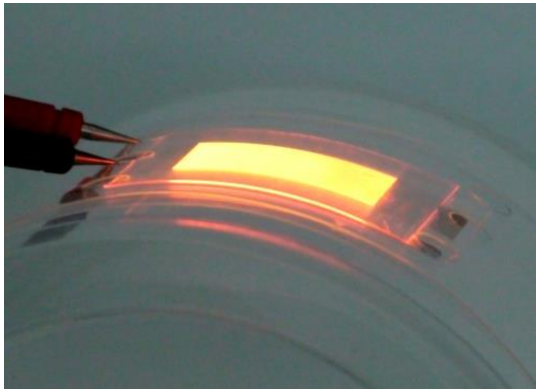
TECHNOLOGIES FOR ORGANIC ELECTRONICS



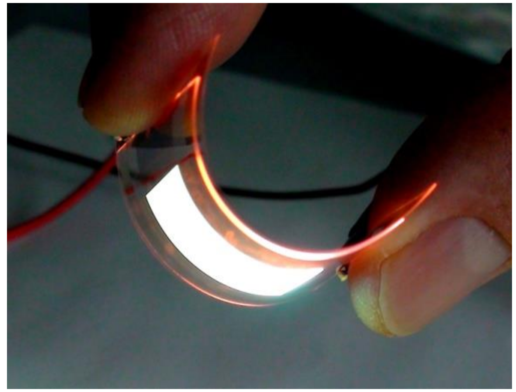
IC AND SYSTEM DESIGN

FUTURE OLED LIGHTING WILL BE FLEXIBLE

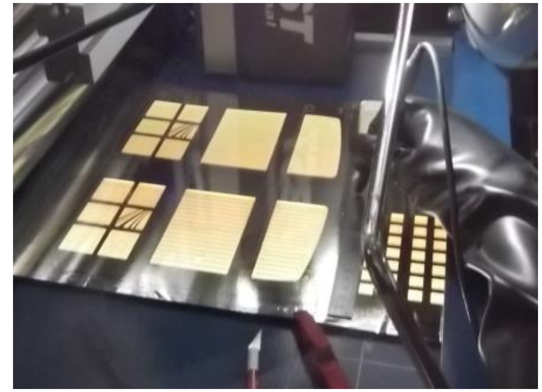
Thin glass



Plastic foil



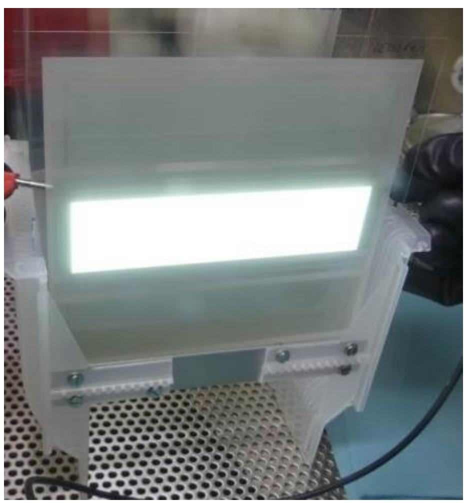
Metal foil



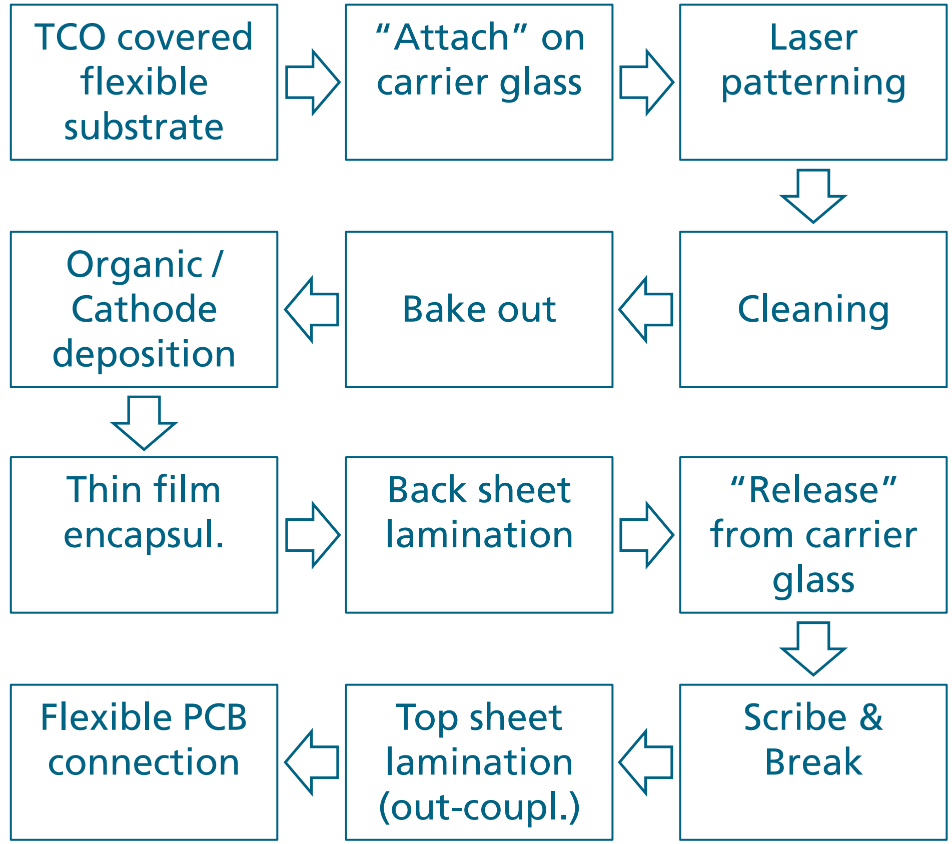
- What means „FLEXIBLE OLED“?
- folded? wrapped? rolled? twisted? „crumpled/creased“? curvable? bendable? conformable?
- with neglible effect on its electronic function
- consensus : use of flexible substrate
- Different applications ask for different types of „Flexibility“!
- 1-dimensional, 1.5-dimensional, 2-dimensional curvature

SHEET-TO-SHEET PROCESS OLED ON ULTRA THIN GLASS (UTG)

- Carrier glass: 200x200x0.7mm³
- substrate: 100µm UTG
- back sheet: 100µm UTG



before „release“



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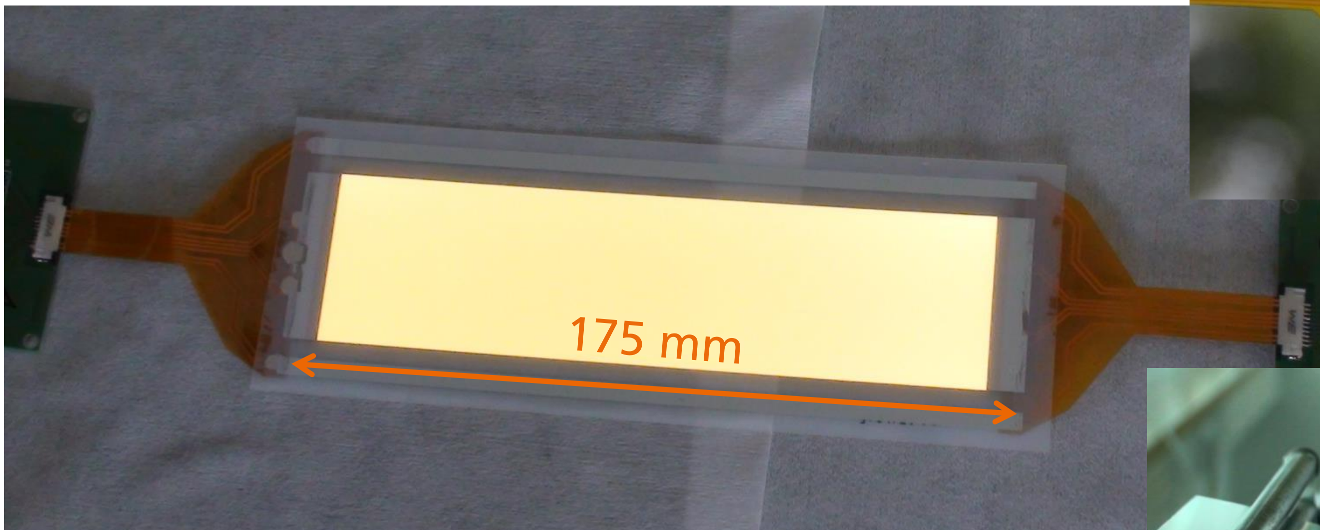
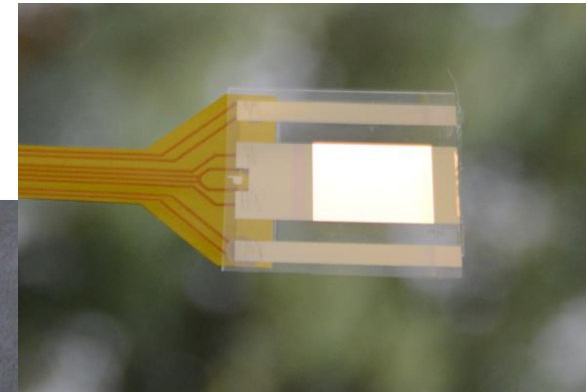
OLED ON FLEXIBLE ULTRA THIN GLASS BY SHEET-TO-SHEET PROCESSING





- Substrate and encapsulation: 100 µm ultra-thin glass, each + out-coupling foil: 130 µm
- Active area: 62 cm² (active area: 15,5 x 40 cm²)
- Module size: 18.3 x 66,3 cm²
- Bottom emission @ 1000 cd/m²

current	**voltage**	**lum.efficacy**	**Color coordinates**		**CCT**	**CRI**
[mA]	[V]	[lm/W]	C.I.E. x	C.I.E. y	[K]	[%]
80	8.19	32.4	0.386	0.382	3895	83

OVERVIEW PROCESS FLOW IN R2R R&D LINE

R2R inspection system

R2R vacuum coater

R2R printing and lamination unit (N_2)

Substrate Inspection → Structuring → Substrate inspection → Vacuum coating → Encapsulation → OLED characterisation

- Typically **300 mm** web width
  - metal strips: thickness up to 500 µm
  - **polymer webs : thickness 50 to 500 µm**
  - **flexible glass : thickness 50 and 100 µm preferably (“pure” or laminated on PET)**

100 x 100 mm² devices on barrier film

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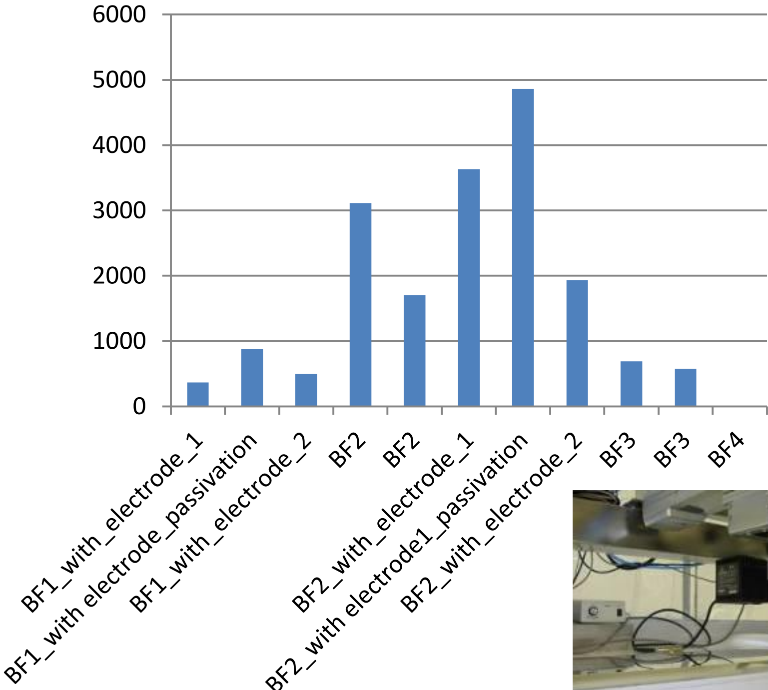
Defect Density Measured by the Optical Microscope (5x Objective)

Spot Counting, defect density on barrier films [cm^{-2}]



Substrate	average defect density [1/cm^2]
Melinex 400 CW coating side	1840 ± 410
Teonex Q65 FA	6.6 ± 2,8
After winding of TEONEX Q65FA in *labFlex® 200*	635 ± 75
After coating of ZTO, 100 nm on TEONEX-Film	141 ± 57
PECVD-Coating of $[(CH_3)_2$-Si-$O]_n$-Plasmapolymer	4950 ± 41

- High variation of the defect density on barrier films
- Defect generation by winding and coating → reliable correlation with WVTR value?
- Development of specification together with barrier film supplier necessary.

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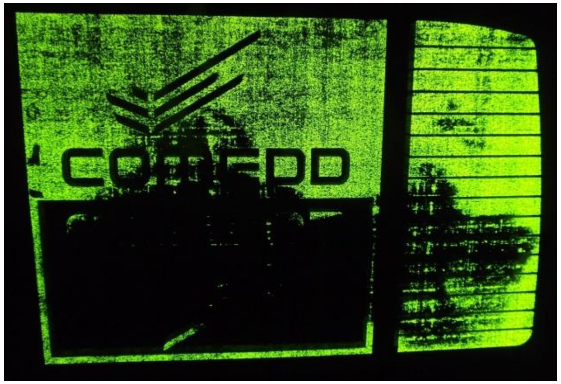
Process Developement for Roll-to-Roll Drying of Barrier Films



Barrier film not dried before OLED process.

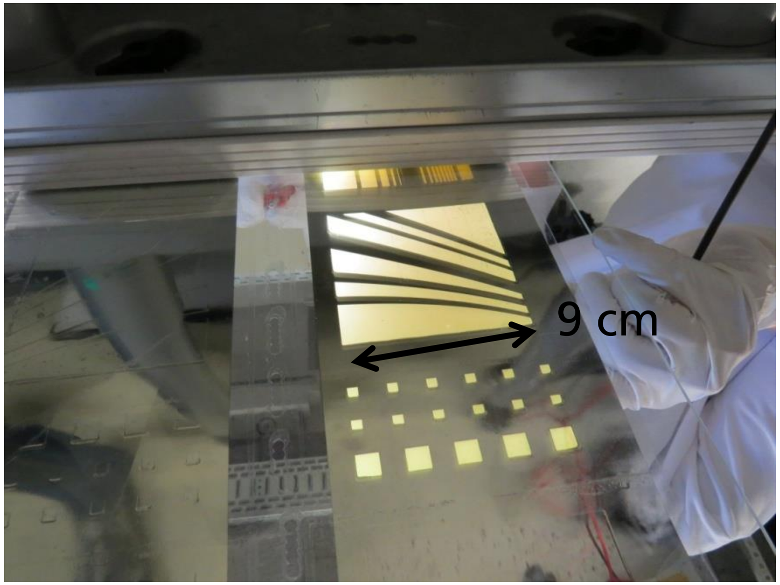
Barrier film dried for 10 minutes at 100 °C under N2 condition before OLED process

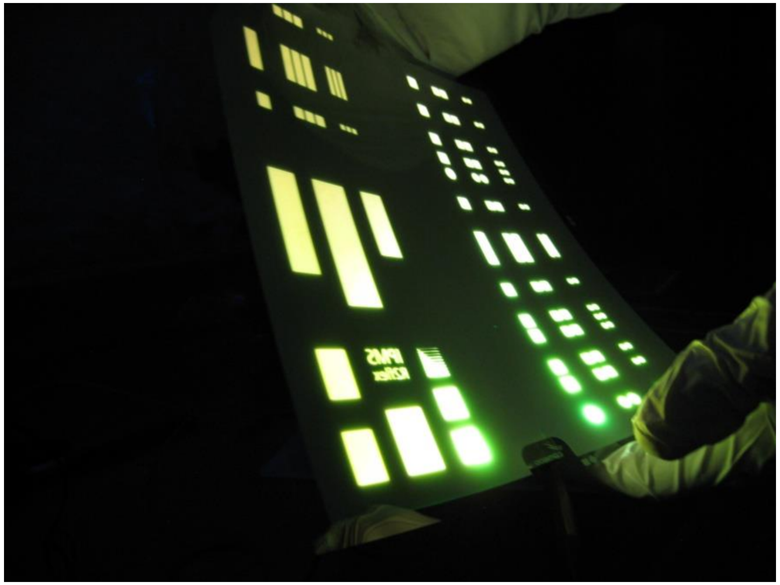
Drying as a significant effect on minimizing straight degradation, but a roll-to-roll process cannot sufficiently dry barrier films stored under ambient conditions!
→ How to tread barrier film rolls to reach water content < 100 ppm?

R2R OLEDs on flexible glass - results

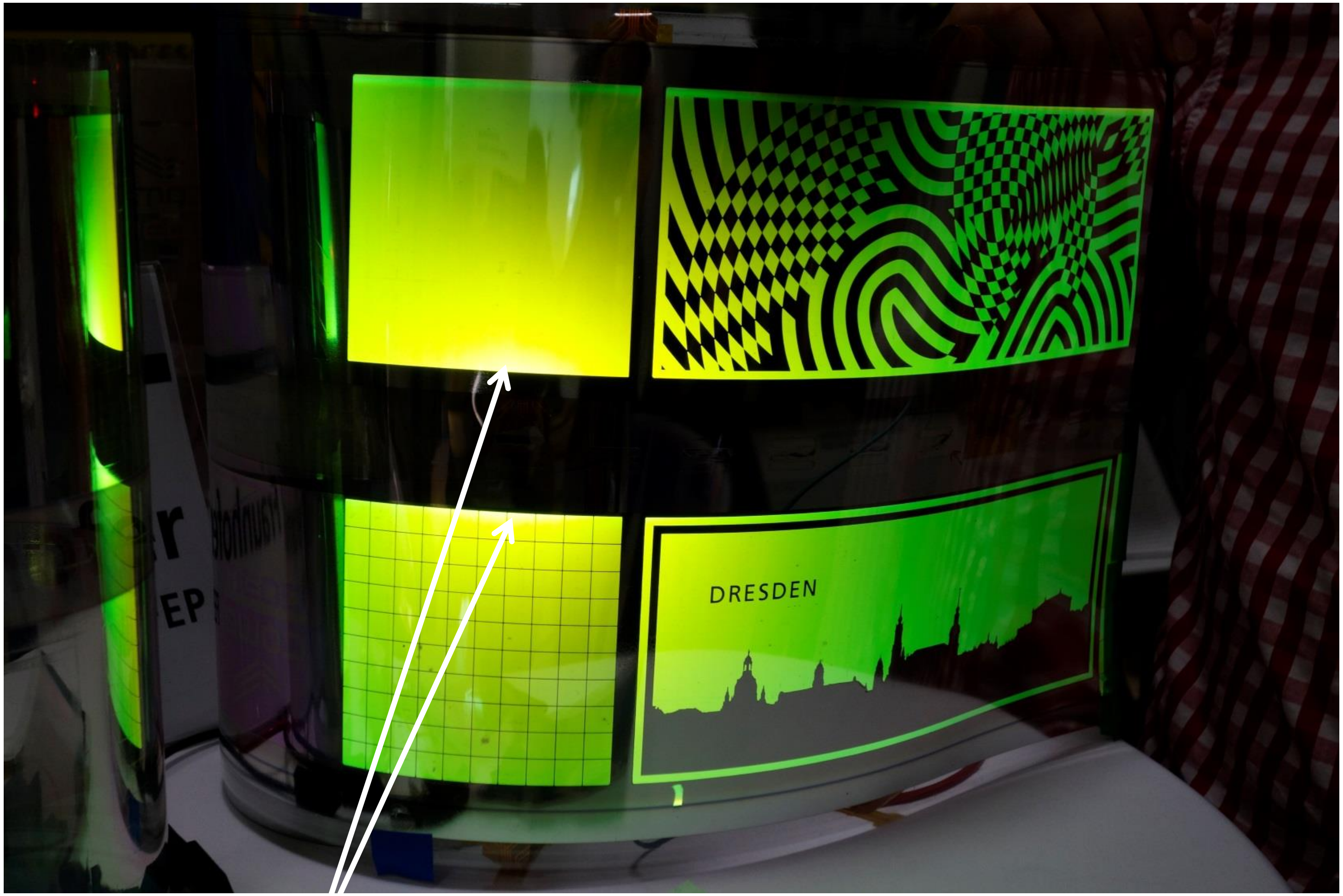
Results on sheets:

- 3 color white fluorescent stack (up to 10 lm/W, CRI 70, up to 9x9 cm²)
- OLED active areas much more homogenous due to “hot” ITO (< 15 Ohm/sq)
- OLED leakage current (10^{-3} down to 10^{-4} mA/cm²) -> substrate defect density 10x smaller than for barrier films: promising regarding OLED stability and lifetime
- sheets delaminate easily from host band (process heat), they need to be stuck to the host band precisely: future R2R deposition on “pure” glass rolls





R2R OLED processing on thin glass



Challenging: Reliable electrical contact with low contact resistance for large area illumination (local high current density at the contact).

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TREASORES – Transparent Electrodes for Large Area, Large Scale Production of Organic Optoelectronic Devices

- Project (funded by the EC, 11/2012 – 10/2015) has developed and scaled up the production of several new transparent electrodes and barrier materials for use in the next generation of flexible optoelectronics:
  - 3 of these ITO-free electrodes on flexible substrates that use either carbon nanotubes, metal fibers or thin silver are now being produced commercially (T> 80%, Rs < 10 Ohm/sq, < 30 €/m^2),
  - high performance (WVTR 10-3 g/m^2day at RT/50°) low-cost barriers (<5,5 €/m^2) on PET foils were developed and it is expected that the new technology will be commercialized - such high performance barriers are essential to achieve the long device lifetimes,
  - the new electrodes and barriers have been tested with several types of optoelectronic devices using rolls of over 100 m in length, and found to be especially suitable for next-generation light sources like OLEDs (PE > 25 lm/W) and solar cells ($\eta > 5\%$),
  - by combining the production of barriers with electrodes (instead of using two separate plastic substrates), the project has shown that production costs can be further reduced and devices made thinner and more flexible.

FP7-FoF-ICT-2011.7.2
Grant agreement No.
314068

R2D2 – Research Consortium for flexible OLEDs in Germany
Light in a new shape

- System integration of flexible OLED modules for the use in automotive, avionics and white goods
- Production capable processes and technologies for flexible OLED and principle aspects of long-living devices, efficacy and homogeneity
- Direct involvement of renowned lighting manufacturers and their end users shall leverage a faster and more holistic exploitation of the project results after the end of the project
- Project consortium covers the complete value chain:
  - material research (Novaled)
  - equipment (VON ARDENNE)
  - device technology (OSRAM OLED, Fraunhofer FEP)
  - automotive application (AUDI, Hella)
  - avionics and white goods application (Diehl)
- funded by BMBF with a volume of 5.9 Mio €:
  October 2013 until December 2015
  Project coordinator: Dr. Christian May, Fraunhofer FEP

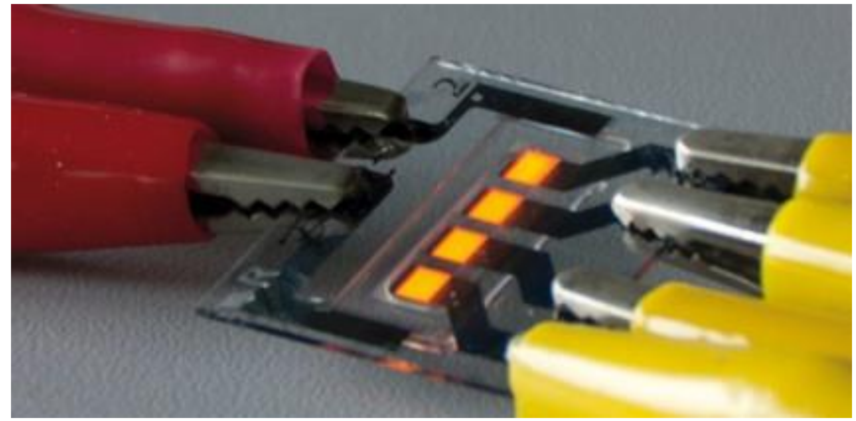
Audi Vorsprung durch Technik
novaled
VON ARDENNE
HELLA
DIEHL
OSRAM
Fraunhofer FEP

source: OSRAM OLED

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

GRAPHENE AS TRANSPARENT ELECTRODE FOR OLED

- Sophisticated material properties of graphene must be maintained during the integration in organic devices => several methods for cleaning and structuring the graphene must be modified
- Processes for different target substrates such as glass or flexible foil must be adapted and optimized
- First hurdles have been overcome => first defect-free OLEDs on transparent graphene electrodes realized on small areas
- Fraunhofer FEP showed for the first time OLED on graphene at Plastic Electronics, 6th – 8th Oct. 2015
- Target 2017
  - white OLED with an area of about 42 cm^2 to demonstrate the high conductivity
  - fully-flexible, transparent OLED with an area of 3 cm^2 to confirm the mechanical reliability



GLADIATOR - „Graphene Layers: Production, Characterization and Integration“- funded by the EC (GA no. 604000)

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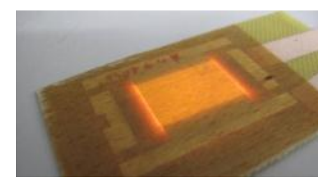
SUMMARY

- OLED as a next generation flat and flexible light source: conformable modules using flexible substrates allow for much more design freedom and integration
- Efficiency and lifetime ready for first products, cost reduction within the next years expected

- Roll-to-roll OLED manufacturing with low priced substrate and for mass production has a high potential for low cost (manufacturing on sheets needs a bonding, de-bonding process on a carrier).
- Roll-to-roll OLED process can be reproducible performed on metal-, plastic- and ultra-thin glass web
  - Still high variation of dark spots and leakage current

  - OLED lifetime at 1000 cd/m² > 5000 h and power efficacy of > 25 lm/W could be possible.
  - Challenges to remove residual water in barrier films in roll-to-roll with understanding of drying kinetics → low WVTR values makes customer not happy only!
  - Improvement of web handling in the equipment is necessary, but solvable (just a matter of investment)



  - Optimization of the R2R cleaning process to bring particle level down to minimize dark spots (particle size > adhesive thickness)
    - Control dark spot forecast and density
    - Forecast with the yield for a certain substrate surface quality
- Understanding of the barrier adhesion, mechanical stability and reliable electrical contacts necessary